Fast lifetime measurements of infrared emitters with low-jitter superconducting single photon detectors

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Abstract: We use a superconducting single photon detector with ~65 ps jitter and <40 Hz dark count rate to measure spontaneous emission lifetimes of quantum wells emitting light in the 900-1300 nm wavelength range.

OCIS Codes: (230.5160) Photodetectors; (160.6000) Semiconductors, including MQW; (320.5390) Picosecond phenomena

Time-resolved measurements of photoluminescence (PL) have long been an important tool for materials characterization. Various devices and techniques exist, including streak cameras, cross-correlation upconversion, spectral interferometry and frequency-resolved optical gating. While virtually all of these techniques are suitable for measuring light in the visible and near-infrared, some are limited to bright sources, and many are restricted to wavelengths $\lambda < 1$ μm.

Time-correlated single photon counting (TCSPC) provides one straightforward method of measuring spontaneous emission lifetimes. Because it uses detectors—typically avalanche photodiodes (APDs) or photomultiplier tubes (PMTs)—that are sensitive to a single photon, TCSPC is well-suited to very weak sources such as single molecules or quantum dots. Low-jitter detectors and fast electronics have advanced the time resolution of TCSPC into the picosecond range. Performing measurements for $\lambda > 1$ μm requires suitable detectors, but silicon APDs and most PMTs are insensitive in this range. InGaAs APDs have reasonable detection efficiencies in the infrared, but suffer from very high dark count rates, limiting their use to bright sources.

Recently, superconducting single photon detectors (SSPDs) have been developed that can offer considerable advantages over conventional detectors [1-3]. SSPDs have been demonstrated with up to 20% detection efficiency [1] and time jitter as low as 20 ps [2]. Their principle advantage, however, is that they are sensitive well into the infrared. Since SSPDs must be operated at temperatures near 4 K, we have packaged SSPD devices in a practical, turnkey, cryogen-free system using a commercially available cryocooler [3].

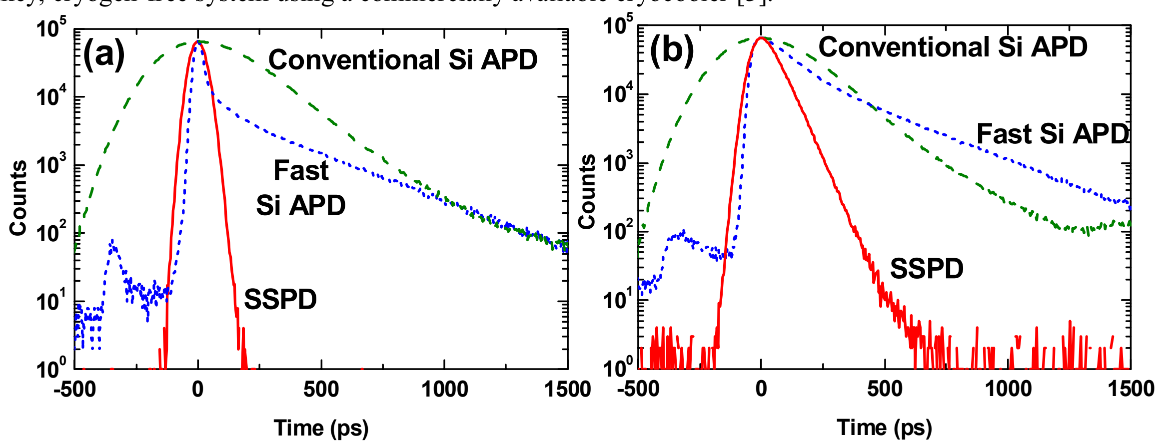

Fig. 1. (a) Instrument response function comparison of 3 detectors. (b) Lifetime measurement of QW emission at 935 nm with 3 detectors.

Here, we use an SSPD to measure the spontaneous emission lifetimes of two semiconductor quantum wells (QWs) that emit at 935 nm and 1245 nm. Each QW sample is optically pumped with a Ti:Sapphire laser that produces ~1 ps pulses with a center wavelength of 780 nm at 82 MHz repetition rate. PL from the sample is collected with an objective lens, spectrally filtered with a monochromator, and coupled to a single mode fiber. The fiber carries light to the SSPD inside a cryocooler. The SSPD consists of a 100 nm-wide wire of superconducting niobium nitride meandering over a 100 μm^2 area. When the wire absorbs a photon, it momentarily creates a hot spot, forming a voltage drop across this resistive section of the track and sending a high-speed voltage pulse down a transmission line. This pulse starts a timer that stops on the 82 MHz clock signal from a fast photodiode; this reverse start-stop configuration is typical of TCSPC. The start rate is kept << 82 MHz to ensure an average of << 1 count per pulse. The electronics introduce time jitter of < 30 ps and produce the count versus time histograms shown in Figs. 1-2.

To measure the instrument response function (IRF) of a detector, we tune the monochromator to 780 nm and heavily attenuate the laser. The SSPD's IRF (solid red curve in Fig. 1a) is fit well by a Gaussian with a FWHM of ~65 ps. For comparison, Fig. 1a also shows the measured IRFs of a conventional silicon APD (dashed green, FWHM ≈ 400 ps) and a fast Si APD (dotted blue). Although the fast APD has a very narrow main peak (FWHM ≈ 40 ps), it also has an exponential tail that persists for several hundred picoseconds. The advantage of the SSPD over these two detectors is evident in Fig. 1b, which shows lifetime measurements of a GaAs/InGaAs QW (QW1). This QW has an emission peak at 935 nm and was chosen for its relatively short lifetime. Although the SSPD has a fairly low detection efficiency (~2% at 900 nm) [3], its low dark count rate (~20-40 Hz) allows measurements with several decades of dynamic range. Also, the Gaussian shape of the SSPD's IRF should make identification of multi-exponential processes far easier.

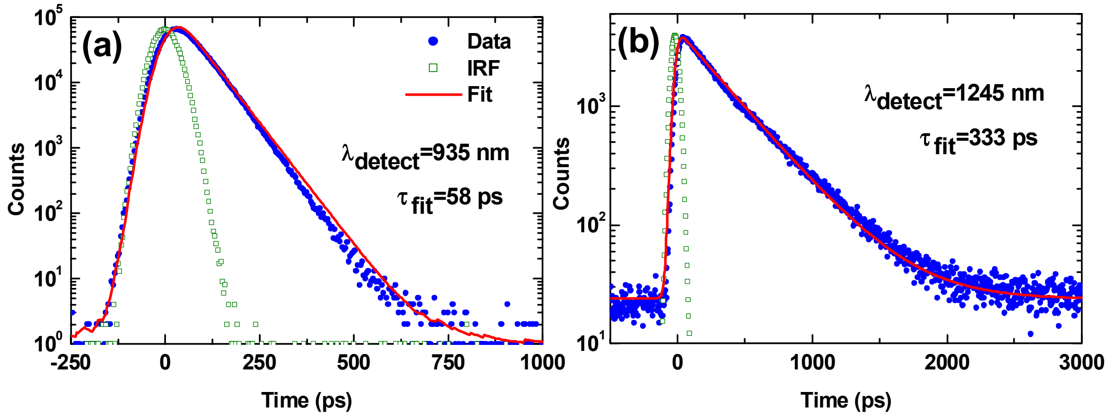

Fig. 2. SSPD lifetime measurements: IRF, measured decay and fit for (a) QW1 at 935 nm and (b) QW2 at 1245 nm.

Fig. 2a plots the SSPD IRF and decay data from Fig 1, along with a fit. This fit is a convolution of the IRF with an exponential with decay constant of 58 ps. Fig. 2b shows similar data for a GaAs/GaInNAs double QW at 1245 nm: here the fit has a decay time of 333 ps. The data in Fig. 2b could not have been acquired using either of the Si APDs used in Fig. 1, since Si APDs have essentially zero quantum efficiency at 1245 nm. We have also measured lifetimes of other QWs emitting between 900 and 1300 nm (not shown). In addition, we recently demonstrated that SSPDs are sensitive enough to measure the lifetime of a quantum dot single photon source [3].

In summary, we have demonstrated the use of a novel superconducting single photon detector for lifetime measurements in the infrared, which should have many applications in characterizing weakly emitting materials, as well as any other application that requires high time resolution in the infrared region of the spectrum, beyond what a Si APD can detect. In addition, the pure Gaussian response function of the SSPD allows us to more accurately measure lifetime compared to a fast Si APD because of the complications caused by the extended tail of the Si device.

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